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PRESENT PROBLEMS IN SOIL PHYSICS AS RELATED TO PLANT ACTIVITIES[1]

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IT is from the point of view of the physiologist and not from that of the analytical physicist that I propose here to consider some of the most obvious and insistent of the non-chemical problems of the soil. We shall thus be interested not in the physics of the soil, but in the *relation* of some of its physical properties to certain plant activities. This is a somewhat unusual point of view, for most soil investigators have studied the soil largely to the exclusion of the plant, bringing refined chemistry and physics to the statement of one member of the equation and stating the other member largely from the standpoint of the unscientific man. This generalization applies to studies upon both the physics and the chemistry of the soil, but, owing to the majesty of the great chemist Liebig[2] and to the multitude of his followers, soil physics has nowhere received the attention which it deserves, and the relation of the physical condition of the substratum to plant activities remains perhaps the most fundamental and at the same time most neglected of all the various environmental relations.

Since we are certain that the water relation is of exceedingly great importance in the control of plant processes, and since so many other physical soil conditions depend largely upon soil moisture, I shall consider here primarily only the water relation of terrestrial plants

[1] Presented in the Symposium on Problems of the Soil, before Section G, A. A. A. S., at the Washington meeting.

[2] Compare, in regard to the present contention, the title of Leibig's monumental work, "Die Chemie und ihrer *Anwendung* auf Agrikultur und Physiologie," 1846.

below the soil surface. But, as will shortly appear in some detail, to appreciate the problems before us it will be necessary, not only to deal with the internal conditions of the root system together with the external ones of the soil, but also to bear constantly in mind certain relations which obtain above the soil. I shall begin with a brief treatment of the water relations of *the plant,* with special reference to the physical conditions of its subterranean environment.

In order that the water content requisite for the various physiological processes may be maintained, the condition must obviously be fulfilled, that the ratio of *the rate of water income to that of water removal must never fall below unity.* Now, the removal of free water from the physiological system of the plant occurs in three general ways: (1) the fixation of water by growth, etc., (2) the excretion of liquid water at the periphery and (3) the loss of water vapor by transpiration. The first two of these are usually negligible, and the prime aerial condition of plant activity—as far as the water relation is concerned—is the rate of loss of water vapor. This loss is to a variable extent controlled by conditions within and without the plant, but we do not need to give these attention now. The main point for us to bear in mind is that, for the activities of the majority of terrestrial plants, it is requisite that the entrance of water through the roots must equal its rate of exit through the leaves and other aerial parts.

Of course water will not, in general, enter through the roots faster than it is removed from the plant body or fixed therein by growth and metabolism, and the critical consideration in respect to the soil water relation is not the actual rate at which water *is entering* (this depending upon the internal conditions of the plant as well as upon the soil), but the *maximum possible* rate at which it may enter if the prerequisite internal conditions arise. In this respect, then, that soil is best suited to continued physiological activity, which possesses the highest power

of supplying moisture to the absorbing regions of the plant.

It would seem, *a priori,* that a flooded soil should offer the least possible resistance to water movement, but such a soil appears indirectly to reduce water entrance in many forms by influencing (probably directly or indirectly in a chemical way) the internal conditions of the plant, and it is only with a soil in a considerably drier condition than the flooded one, that we find the optimum subterranean environment for ordinary plant processes. As the soil becomes drier, its direct resistance to water intake by the roots increases, slowly at first, then rapidly, and at a certain stage (for any given complex of aerial conditions, and hence for any given transpiration rate) the combined resultant of the movement of soil moisture to the root surfaces and that of these surfaces through the soil (by growth) falls to a magnitude so low that the processes of transpiration and of growth, etc., remove water from the tissues more rapidly than it enters below. This condition of the substratum is approximately what is usually termed the wilting point, and the remaining water in the soil is said to be unavailable for plants.

In researches which have yet to be published, my associates and I have shown that this wilting point is not the constant which it has been supposed to be, for either soil or plant. It is possible to cause the lower limit of "available" water in the soil to assume almost any magnitude, within a broad range, for any given plant, merely by altering the rate of transpiration,—through proper changes in the evaporating power of the air and the intensity of the impinging solar radiation. The wilting point thus ceases to have any meaning at all, unless the corresponding rate of transpiration is known, or unless, indeed, the aerial environment is known to be the same throughout any series of cultures the data from which are to be compared.

The primary problem, then, which must be quantitatively solved if we are to place the soil water relation in

a way that may lead to a scientific foundation, is concerned with the maximum rates at which various soils may furnish moisture to the root systems of whatever plant forms with which we may be dealing. To such an end, our knowledge of the physiology and ecology of roots must be enormously increased, but with this phase of the matter we need not here concern ourselves. It is obvious, however, that the really crucial question with regard to any soil, the properties of which we wish to study with reference to plant behavior, is this: *at what rate, and for how long a time, can it deliver water to unit area of a water-absorbing surface?* This is a purely physical question and one for which it ought not to be very difficult to find adequate methods of attack. Indeed, the method of studying evaporation from soil surfaces already offers approximate results in this direction.

This maximum rate of delivery per unit of cross section must be related in some manner to the soil characters which are now often measured; the power of water delivery will vary with the percentage of water content for any particular soil, and its graph will most likely exhibit a critical point under about the same conditions as those which accompany the critical points for evaporation from the soil, the apparent specific gravity of the latter, its penetrability (as recently brought out by Cameron and Gallagher), its critical moisture content and its moisture equivalent (as brought out by the centrifugal method of Briggs and McLane). That the critical point in maximum rate of delivery of moisture will be found to correspond to the ordinarily observed optimum water content for many plants is also to be expected, but the physiologist will not make the mistake of supposing that this optimum water content will not vary largely with the nature and condition of the plant and also with its rate of transpiration. That this critical point, with soils of varying water content, will be found to be related to the size, nature and arrangement of the soil particles is likewise fairly certain, and it may confidently be ex-

pected that this point will exhibit some definite relation to the heat of wetting (as this property has been developed by Mitscherlich), and perhaps also to the commonly determined water capacity or water-retaining power of the soil. The last named is a property which, as I have previously pointed out, seems especially worthy of investigation by ecologists who are seeking some easily determined soil characteristic for use in studies on plant distribution.

In this connection it is well to call attention to the apparent futility of the method of mechanical analysis, which is resorted to so extensively—and so expensively—in attempts physically to describe the solid portion of the soil. I think I do not exaggerate when I say that the physical analysis has shown itself to be practically worthless for any physiological purpose. It assuredly does furnish a means of describing a given soil sample with considerable accuracy, and if two samples could ever be found to exhibit exactly the same proportions of the different sized particles, it might plausibly be supposed that, *ceteris paribus,* these should possess the same relations toward water and toward plant roots, but the converse of this statement is not at all true. This method furnishes a mass of data from which no one has yet been able to derive any single comprehensive summation that will express anything definitely as to the possibilities of the given soil as a substratum for plants. Undoubtedly the size of the component soil particles plays a large part in determining how the water conductivity varies with different conditions of soil moisture, etc., but we need to seek some feature which may be much more readily measured for the soil as a whole than merely the proportions of various-sized particles.

Should we be able to find out the relations which obtain between the maximum rate of water delivery and the other soil characters that I have mentioned, it might at length become possible physically to assay a given soil by the determination of one or more of the latter, sub-

sequently passing to the real point of interest by means of an interpretation, but such a possibility is at present so far removed from actuality that it seems highly desirable to begin with attempts to measure the soil property which directly influences plants. In any event, it can not be too strongly emphasized that such soil studies as I am suggesting must always be carried on simultaneously with studies on the behavior of plants, and also with adequate determinations of the water-extracting power of the aerial environment. It seems quite likely that we shall be able empirically to determine some highly important principles bearing upon the water relations which exist between plants and soils, without having yet succeeded in analyzing the mode of manifestation of these into its elementary physical propositions—just as it has recently been possible to work out exceedingly valuable principles with reference to the relation of plants to evaporation, without any one's having yet succeeded in determining the quantitative dependence of this climatic factor upon its components, water and air temperature, air humidity and air movement.

When a little headway has been gained in the dynamic study of the soil in relation to plant processes, we shall probably begin to be able to interpret and correct, and place upon a proper quantitative basis, some of the ecological classifications of plants and the physical classifications of soils, which already occupy so much of our literature.

Another aspect of this whole question of the water relations of the subterranean parts of the terrestrial plant may be worthy of attention. The majority of the physical soil studies which have so far been made depend upon the removal of the soil sample from its natural position, with consequent and usually profound alterations in the arrangement of its component grains, upon which arrangement assuredly depend some of the most fundamental of the soil qualities which we need to know about. Various methods have been devised aiming to

avoid this difficulty, but all are exceedingly cumbersome in the operation and are at best of somewhat doubtful efficiency. Here is suggested a line of work which has already been attempted by a number of enthusiastic students, many of whom have afterward given up in despair without even publishing their experience. The director of one of the great European experiment stations told me of a somewhat elaborate apparatus which he once constructed for determining soil moisture *in situ*. He concluded with the remark, "the principle was correct enough, but the method proved useless." I am sure that he is not alone in his experience. But the problem of soil instrumentation will not be dropped; I am confident that the future will develop methods in soil physics which will not necessitate any alteration in the soil at the time a determination is made. Studies upon the soil properties in the light of their rôle in plant environment and accompanying studies on the physics of plant activities will do much toward furthering our science in this direction. The actual accomplishment of this end may not be very far off; we may take heart from such facts as this, that a single decade has sufficed to bring aerial navigation from the limbo of scoffed-at impossibility (in the minds of all but a very few scientists) into the category of accomplished fact. And the importance of adequate methods for the study of problems of the soil is far greater, and probably will ever remain far greater, than that of any problem of transportation.

To summarize my suggestions:

1. The soil water relation is of fundamental importance if we are some time to know about and be able to predict and control plant processes.

2. The moisture of the soil, as well as its other features, is most profitably to be studied as plant environment, the *relations* which obtain between plant activity and soil phenomena comprising a fundamental and primary requirement for the scientific advance of our knowledge.

3. The physical nature of the subterranean environment of terrestrial plants is effective in controlling plant activities, mainly with regard to the possible rate of delivery of water by the soil to unit area of absorbing roots.

4. It is highly desirable to study this power of water delivery with reference not only to the growth of plants but also to other soil characteristics, some of which are already commonly measured.

5. The whole problem of the physics of the subterranean surroundings of rooted plants awaits the development of an instrumentation which will not necessitate the preliminary destruction of some of the most important soil properties before the soil can really be studied.